THE EXISTENCE OF PLANETS ABOUT THE FIXED STARS.

By T. J. J. SEE.

(*Read April 23, 1910.*)

The question of the existence of planets about the fixed stars is an old one, and has been more or less discussed by astronomers ever since the popularization of Copernican doctrines by Giordano Bruno, who suffered martyrdom at Rome in the year 1600. Up to the present time, however, there has been no rigorous criterion for the construction of a conclusive argument; and the discussion has been comparatively unprofitable, except in the development and expression of free opinion. Disputations leading to the expression of individual opinion may be of some value, because new ideas may thus be suggested, and accordingly such habits have been encouraged since the days of the Greeks, as we learn from the collections of opinions handed down by such writers as Diogenes Laertius.

But to render such efforts effective from a scientific standpoint it is necessary to find criteria which make it possible to build up a conclusive argument. The discussion then ceases to be a mere record of individual opinion, and becomes an integral part of science supported by the necessary and sufficient conditions required to ensure the validity of accurate mathematical reasoning. This improvement in our knowledge of the existence of planets about the fixed stars has been made possible by the writer's recent discoveries in cosmical evolution, and we shall, therefore, give a brief summary of the argument as it stands today.

So long as we did not know the exact process involved in the formation of the solar system it was possible to argue that just as planets exist about our sun, so too, they may by analogy be inferred to exist also about other fixed stars. This natural inference rests on the implied uniformity of the creative process involved in the development of the planets. Obviously we could not observe planets at the great distance of the fixed stars, while the double and multiple stars constitute systems of very different character. There was, therefore, no direct observational evidence that planetary formation was a part of the usual order of nature. The process by which our solar system arose was involved in great doubt and obscurity, and could not be definitely made out, notwithstanding the labors of many eminent mathematicians during the past century. No longer ago than 1906 the late Professor Newcomb declared[1] that he still retained "a little incredulity as to our power in the present state of science to reach even a high degree of probability in cosmogony."

I have recently shown that the principal difficulty in all the efforts of mathematicians for solving the problems of cosmogony has arisen from false premises which had come down from the days of Laplace, and thus vitiated all our reasoning. It had been uniformly assumed that the planets were thrown off from the sun, and that this process of detachment by rotation of the central mass had set them revolving in orbits of small eccentricity. Laplace's postulates in some form or other had been assumed by all investigators since 1796. And it is curious to notice that Laplace in turn had merely extended the conceptions developed by Newton in his treatment of the problem of the figure of equilibrium of a rotating mass of fluid.

For, in establishing the theory of universal gravitation, in 1686, Newton had correctly explained the figures of the earth and other planets as due to the effect of gravitational attraction combined with the centrifugal force due to axial rotation, thus giving various degrees of oblateness depending on the intensity of the forces, and the heterogeneity of the planetary masses. These results followed from the theory of gravitation, and Newton had applied to them the same masterly reasoning which he usually exhibited in the treatment of mathematical problems.

Not long after the epoch of Newton the problem of the determination of the figures of equilibrium of rotating masses of fluid was considerably improved by the researches of Maclaurin, while subsequently Laplace himself extended and confirmed the results

[1] In *Popular Astronomy* for November, 1906, p. 572.

of his predecessors. Though they did not deal with definite cases of extreme oblateness, the great mathematicians of the eighteenth century made it clear that very rapid rotation would be adequate to produce disc-shaped figures of equilibrium.

This subject is quite fully discussed by Laplace in the "Mécanique Céleste,"[2] where the following theorems are announced.

> Any homogeneous fluid mass of a density equal to the mean density of the earth, cannot be in equilibrium with an elliptical figure, if the time of its rotation be less than 0.10090 day. If this time be greater, there will always be two elliptical figures, and no more, which will satisfy the equilibrium. If the density of the fluid mass be different from that of the earth, we shall have the time of rotation, in which the equilibrium ceases to be possible, with an elliptical figure, by multiplying 0.10090 day by the square root of the ratio of the mean density of the earth to that of the fluid mass. Therefore with a fluid mass whose density is a quarter part of that of the earth, which is nearly the case with the sun, this time would be 0.20180 day, and if the earth were supposed to be fluid and homogeneous, with a density equal to a ninety-eighth part of its present value, the figure it must take to satisfy its present rotatory motion, would be the limit of all the elliptical figures, with which the equilibrium could subsist.

What Laplace here points out was in fact established by Maclaurin in his "Treatise on Fluxions," Edinburgh, 1742. For if k^2 be the gravitational constant, the density of the mass and ω the angular velocity of rotation, then it was proved that for

$$\frac{\omega^2}{2\pi k^2\sigma} = 0.22467$$

the two possible figures of equilibrium coalesce into one, but for

$$\frac{\omega^2}{2\pi k^2\sigma} > 0.22467,$$

there is no ellipsoid of revolution which is a figure of equilibrium. For very small values of $\omega^2/2\pi k^2\sigma$, there are two distinct ellipsoids which are figures of equilibrium, one of them being nearly spherical and the other very oblate, the limits, for $\omega = 0$, being respectively a sphere and an infinite plane.[3]

[2] Liv. III., Chap III., § 20.

[3] Tisserand's "Mécanique Céleste," Tome II., chap. VI.

If a very flat disc could exist as a figure of equilibrium, it was natural to imagine that such figures might have had a part in starting the planets in their round orbits. The great roundness of the orbits of the major planets and of the satellites then known, and their uniform direction of motion near a common plane suggested to Laplace that these orbits had once been nearly circular, and that the bodies had developed from rings like those of Saturn. It appeared to him that they had resulted from the condensation of rings of vapor gently detached from the equators of the bodies which now govern their motions. This reasoning of Laplace was logical, and necessarily resulted from the researches of Newton on the figures of equilibrium of rotating masses of fluid, and the subsequent extension of these researches by Maclaurin, D'Alembert and other mathematicians; and the procedure seemed so plausible that its correctness was assumed by all subsequent investigators.

Thus Lord Kelvin, Newcomb, Darwin, Tisserand, Poincaré and others accepted the principles of Laplace as laid down in his formulation of the nebular hypothesis, and proceeded to work out the details of planetary development. It is true that Kirkwood, Pierce and others had made objections to the Laplacian hypothesis, based on the inability of a medium so rare as the postulated nebula to transmit hydrostatic pressure from the center outwards, but such destructive criticism was of little avail so long as the roundness of the orbits could be explained only by Laplace's hypothesis of detachment. The persistence of Laplace's classic nebular hypothesis, in spite of negative criticism, was therefore inevitable. But as the greatest mathematicians were unable to make out the process of planetary formation, on the detachment theory, the whole subject remained one of contradiction and obscurity. In his address to the British Association at Capetown, in 1905, Professor Sir G. H. Darwin said:

> The telescope seems to confirm the general correctness of Laplace's hypothesis. . . . Nevertheless it is hardly too much to say that every stage in the supposed process presents to us some difficulty or impossibility. Thus we ask whether a mass of gas of almost inconceivable tenuity can really rotate all in one piece, and whether it is not more probable that there would be a central whirlpool surrounded by more slowly moving parts. Again, is there any sufficient reason to suppose that a series of intermittent efforts would

lead to the detachment of distinct rings, and is not a continuous outflow of gas from the equator more probable? (p. 19).

So the matter stood until early in 1908, when the writer took up study of the spiral nebulæ and discovered that the roundness of the orbits of the planets and satellites was due to the secular action of a resisting medium, and not to detachment in orbits which were originally nearly circular, as imagined by Laplace.[4] The novelty of this view of the formation of the solar system is pointed out in a review by a distinguished authority in *Nature* of July 29, 1909, where we read:

> Dr. See contends that the planets and satellites of the solar system were captured and their orbits made remarkably circular by a resisting medium. In his view, therefore, Laplace's nebular hypothesis is altogether wrong, whereas the current view is that it is in the main right, though in need of considerable modification and extension. . . . Capture is a possibility, but Dr. See has done nothing to raise his theory beyond a mere conjecture, even though he points out, in addition, that a resisting medium would diminish the mean distance and the eccentricity of an elliptic orbit, and that in the case of Jupiter's satellites the outer orbits are highly eccentric and the inner orbits nearly circular.

This review was written before the papers on the dynamical theory of the capture of satellites,[5] and the capture of the moon[6] had appeared; so that the claim that I have not explained how capture takes place is no longer valid. On the contrary, this work has now been published nearly a year, and the correctness of it does not seem to be questioned in any quarter.

We shall not in this paper dwell on the work done by the author during the past two years, and embodied in Volume II. of the "Researches on the Evolution of the Stellar Systems," which is soon to appear, but shall merely remark that the Laplacian theory now appears to be permanently overthrown and the capture theory established in its place. It is proved that the embryo planets were formed in the outer parts of the solar nebula, and have been captured and attached to the sun after nearing it from a great distance, while the satellites have been likewise captured by their several planets.

[4] Cf. *A. N.*, 4308.
[5] *A. N.*, 4341–2.
[6] *A. N.*, 4343.

This proof that the planets never were any part of the sun, but have come to it from great distance, is accompanied by an argument based on dynamical principles showing that the same thing will happen for any other star developing in a nebula; and it is, therefore, certain that the other stars have planetary systems revolving about them. The argument is based on the recognized laws of dynamics and verified by the known history of the solar system, and therefore seems to be entirely satisfactory.

The difficulty and uncertainty, as to the existence of planets about the fixed stars generally, appears, therefore, to be overcome; and we conclude that the discovery of the true process of formation of our system enables us to affirm with confidence that nearly all the fixed stars have systems of planets revolving about them. Here is the foundation of the new line of argument.

1. The observed motions of the double stars show that the law of gravitation is universal, and that the same law of attraction that holds true for the bodies revolving about the sun also regulates the motions of the remotest stars.

2. This indicates that the forces are central, and that the same laws of areas and of motion hold there as in the solar system. Similar effects imply similar causes, and hence the double stars have been set revolving by projective forces and other causes analogous to those which set the planets in motion about the sun.

3. These movements resulted from nebular vortices, formed by the settlement and winding up of streams of nebulosity which did not pass through the center, but circled about it.

4. Such is the phenomenon shown in the spiral nebulæ, which are proved to exhibit the usual process in the development of cosmical systems. Nebulæ are formed from cosmical dust expelled from the stars, and it cannot fall to a center to produce a central sun without giving rise to a whirling vortex about that center, since but few of the streams will converge in a point.

5. Planets form in the streams which make up a spiral nebula, and in some cases they unite to form a double star, the system thus developing into a double sun; but in the more typical case the planets are too small to be seen and the stars appear to be single,

whereas in reality they are surrounded by planetary system not unlike that which revolves about our sun.

6. The spiral nebulæ indicate very plainly that the motion of the nebulosity is towards the center; that it was originally at greater distance, but at length captured and brought in nearer and nearer the center by the action of universal gravitation.

7. It is, therefore, plain that just as our planets were formed in our nebula at a great distance from the sun and afterwards had their orbits reduced in size and rounded up by moving against a resisting medium; so also planets revolving and passing gradually into order and stability are developed in the nebulous streams which by condensation have formed the other stars, and this makes possible the formation of planetary systems among the stars generally.

8. We may, therefore, feel entirely certain that the stars which appear to be single—about four fifths of all the stars—have planets revolving about them. And the other fifth are spectroscopic and visual binaries, the planets in this case being so large as to be visible in our telescopes or producing a relative motion in the line of sight which may be recognized by means of the spectrograph.

9. The historical difficulty of determining whether there are planets about the fixed stars may, therefore, be definitely overcome by the recognition of the true mode of formation of the planetary system. It is not exceptional, as was formerly believed. So long as we held that the planets were thrown off, it was not at all certain that the mechanical conditions would permit such detachments elsewhere in the universe, and our solar system might be held to be nearly if not quite unique. Now, however, all such views become inadmissible, and we see that our system is typical of the general order of nature.

10. Accordingly, although the planets about the fixed stars probably will always be invisible, and too small to be detected by the spectrograph, yet it is possible to be quite sure of their existence from the operation of known mechanical laws; and from the demonstrated mode of formation of the solar system. This is a practical application of the capture theory to the larger problems of the universe, and the result is of general interest to every

student of nature. The "Astronomy of the Invisible" thus takes on vastly greater importance than in the time of Laplace and Bessel. And we see that the sagacious suggestions made by these great astronomers nearly a century ago were well founded. And just as there are invisible planets about the luminous fixed stars, so also there probably are countless bodies everywhere in space which are essentially non-luminous. The amount of dark matter in the universe therefore is much greater than has been generally supposed, or heretofore considered probable.

U. S. Naval Observatory,
Mare Island, California,
March 28, 1910.